Technologies for the Inflation Probe

[Draft – 07/25/11]

Technology	Detectors			Optical system	Cryogenic system	Advanced mm-wave / far-IR Arrays
	Sensor Arrays	**Multiplexing**	**Optical Coupling**			
Brief Description of Technology	The Inflation Probe requires arrays of polarization-sensitive detectors with noise below the CMB photon noise at multiple frequencies between ~30 and ~300 GHz for foreground removal[a]; up to 1 THz for Galactic science.	Multiplexed arrays of 1,000 - 10,000 low- temperature detectors will be required for the Inflation Probe.	The Inflation Probe requires coupling the light to the detectors with exquisite control of polarimetric systematic errors.	High-throughput telescope and optical elements with controlled polarization properties are required; possible use of active polarization modulation using optical elements.	The Inflation Probe requires cryogenic operation, passive radiators, mechanical cryo-coolers, and sub-Kelvin coolers.	Detector arrays with higher multiplexing factors and multi-color operation may provide simplified implementation for the Inflation Probe, and have diverse space-borne applications in X-ray calorimetry and far-infrared astronomy.
Goals and Objectives	Demonstrate arrays in sub-orbital instruments, and demonstrate the background-limited sensitivity appropriate for a satellite-based instrument in the laboratory.	Demonstrate multiplexed arrays of thousands of pixels in ground- and balloon-based instruments.	Demonstrate arrays of polarization- sensitive receivers with sufficient control of polarization systematics in sub-orbital and ground-based instruments.	Demonstrate all elements of an appropriate optics chain in sub-orbital and ground-based instruments.	Develop mature sub-Kelvin coolers appropriate for space.	Develop higher multiplexing factors with micro-resonators; demonstrate multi-color operation with antenna-coupled detectors to reduce focal plane mass.
TRL	**TES:** (TRL 4-5) Noise equivalent power (NEP) appropriate for a satellite has been demonstrated in the laboratory, and TES instruments have been deployed and used for scientific measurements in both ground-based and balloon-borne missions. **HEMT:** (TRL 4) Flight heritage, but extension to 3 QL noise, access to higher frequencies and lower power dissipation requires demonstration.	**TDM:** (TRL 4-5) Ground based arrays of up to 10,000 multiplexed pixels are working on ground-based telescopes. Kilopixel arrays will shortly fly in balloons. **FDM:** (TRL 4-5) Ground based arrays of up to 1,000 multiplexed pixels are working on ground-based telescopes, and initial balloon flights have occurred.	**Planar antenna polarimeter arrays:** (TRL 4-5) Ground based arrays deployed and producing science, balloon-borne arrays will soon be deployed. **Lens-coupled antenna polarimeter arrays:** (TRL 4-5). Ground based arrays deployed. **Corrugated feedhorn polarimeter arrays:** (TRL 4) Corrugated feeds have extensive flight heritage, but coupling kilopixel arrays of silicon platelet feeds to bolometers requires maturation. Ground-based arrays in this configuration are soon to be deployed.	**Millimeter-wave AR coatings:** (TRL 2-5) multi-layer to single-layer coatings. **Polarization modulators:** (TRL 2-4) half- wave plate modulators, variable polarization modulators, or on-chip solid-state modulators	Technology options for the sub-Kelvin coolers include He-3 sorption refrigerators, adiabatic demagnetization refrigerators, and dilution refrigerators. TRL for all options varies considerably from TRL 3 to TRL 9. Planck and Herschel provide flight heritage for some of these systems.	**MKID:** (TRL 3) Appropriate sensitivity needs to be demonstrated, small ground-based instruments are in development. **Microresonators:** (TRL 3) 2,000-channel ground-based MKID instruments are in preparation. Laboratory systems using microwave SQUIDs have been developed for small TES arrays. Hybrid combinations are possible. **Multi-color pixels:** (TRL 2) Multi-band lens-coupled antennas have shown proof of concept, but must meet exacting CMB requirements.
Tipping Point	For the TES, demonstrate appropriate sensitivity at all relevant wavelengths. For HEMTs, improved noise performance and low power dissipation.	For TDM and FDM, demonstrate full- scale operation on a balloon-borne instrument.	Extensive analysis of data from ground-based and balloon experiments is required to demonstrate control of systematics. Demonstrations required at all wavelengths of interest.	Demonstrate relevant optical system designs, including reflective and refractive optics, millimeter AR coatings, and half-wave plate polarization modulators.	Space cooling system can be leveraged on current technology efforts, but must provide extremely stable continuous operation	MKID instruments must demonstrate sensitivity in full sub-orbital instrument. For microresonators, a breakthrough is required on the room-temperature readout electronics. Multi-band pixels must be used in sub-orbital instrument.
NASA Capabilities	National labs (JPL, GSFC, NIST, and Argonne) and University groups (Berkeley) have extensive experience with the design and fabrication of arrays that have been used in previous missions in this wavelength range.			NASA and many University groups have developed and deployed optical systems as described here.	NASA has extensive heritage appropriate to the task, and some elements are commercially available.	National labs (JPL, GSFC, NIST, and Argonne) and University groups (Berkeley) have extensive experience with the design and fabrication of arrays.
Benefit/Ranking	The development of large sensitive arrays is a major breakthrough that enables precision cosmology. Ranking: iv.		The control of systematics required for a measurement of primordial B modes is a major breakthrough that enables precision cosmology. Ranking: iv.	Optical system developments will continue to improve the capability of missions requiring strong control of systematic error.	Cryogenic system developments will continue to improve the capability of any missions requiring sub-Kelvin cooling.	The development of advanced arrays would simplify the implementation of the Inflation probe, if the mission schedule allows this development. Ranking: iii.

			Ranking: ii.	Ranking: ii.	
NASA needs/Ranking	The technology developed would leverage many other missions requiring low-temperature superconducting detectors, including **IXO**, **Generation-X**, and future far-infrared missions such as **SPIRIT**, **SPECs, or SAFIR.** Ranking: iv	Pixel optical coupling technologies are candidates for future far-infrared missions such as **SPIRIT**, **SPECs, or SAFIR**. Ranking: iv	Improvements in optical systems will benefit **SPIRIT**, **SPECs, or SAFIR**. Ranking: iv	Developments will benefit any other future satellite mission requiring sub-Kelvin cooling, including **IXO**, **SPICA**, **SAFIR**, etc. Ranking: iv	The technology developed would leverage many other missions requiring low-temperature superconducting detectors, including **IXO**, **Generation-X**, and future far-infrared missions such as **SPIRIT**, **SPECs, or SAFIR.** Ranking: iv
Non-NASA but aerospace needs	Arrays of sensitive bolometers may have national security applications either in thermal imaging of the earth, or in gamma spectroscopy of nuclear events. Ranking ii.				Arrays of sensitive bolometers may have national security applications either in thermal imaging of the earth, or in gamma spectroscopy of nuclear events. Ranking ii.
Non aerospace needs	Sensitive mm-wave bolometer arrays have applications in remote sensing, including concealed weapons detection, suicide bomber detection, medical imaging, and sensing through fog. Ranking iii.				Sensitive mm-wave bolometer arrays have applications in remote sensing, including concealed weapons detection, suicide bomber detection, medical imaging, and sensing through fog. Ranking iii.
Technical Risk	The technical risk is medium. Commercial solutions do not exist, but multiple university groups, NASA centers (JPL and GSFC), and federal laboratories (NIST) have extensive capabilities. TRL 5 is within reach, and multiple ground- and balloon-borne instruments will be tested in the next few years. Ranking iv.		Individual elements have technical risk (e.g. AR coatings and polarization modulators). Ranking: ii	Most options have some flight heritage but need to meet system requirements. Ranking: ii	The technical risk is medium, assuming a longer development time is available to develop these technologies from their current readiness. Ranking iv.
Sequencing/Timing	Should come as early as possible. The entire Inflation Probe system is dependent on the capabilities of the sensors. Ranking iv		Early test of optical elements needed to gauge system issues.	The cryogenic system is specialized for space and not as time-critical.	These advanced options should be pursued in parallel to reduce cost and implementation risk. Ranking iii
Time and Effort to Achieve Goal	5-year collaboration between NASA, NIST, and university groups. Ranking iii.			Leverage current development for space-borne coolers.	5-year collaboration between NASA, NIST, and university groups. Ranking iii.

[a]Information on foregrounds across a broader range of frequencies (5 GHz to 1 THz) from sub-orbital and ground-based experiments is essential for optimizing the choice of bands for the Inflation Probe.